

ADVANCES IN LIQUID PHASE TECHNOLOGY

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ABSTRACT

The liquid phase methanol (LPMEOH™) process uses a slurry reactor to convert synthesis gas (primarily a mixture of hydrogen and carbon monoxide) to methanol. Through its superior heat management, the process is ultimately suitable to handle synthesis gas generated through gasification of coal, petroleum coke, natural gas, residual oil, wastes, and other environmentally disadvantaged hydrocarbon feedstocks. Apart from production of chemical grade methanol, the process provides economic advantages in the Integrated Gasification Combined Cycle (IGCC) power generation application. Co-production of power and methanol via the IGCC and the LPMEOH™ process provides opportunities for energy storage for peakshaving of electrical demand and/or clean fuel for export. The LPMEOH™ technology has been developed by Air Products and Chemicals, Inc. since the 1980's, extensively proven in a Department of Energy (DOE) - owned process development unit in LaPorte, Texas and selected for demonstration under the DOE Clean Coal Technology Program. The slurry reactor being demonstrated is also suitable for other exothermic synthesis gas conversion reactions, like synthesis of dimethyl ether and other alcohols/oxygenates. This paper presents an overview of LPMEOH™ and other liquid phase technology aspects and highlights the demonstration project at Eastman Chemical Company's coal gasification facility in Kingsport, TN. Commercial aspects of the LPMEOH™ process are also discussed.

INTRODUCTION

With increasing methanol market demand, it was realized by various companies that a breakthrough in technology was required to provide methanol to the market place in a cost competitive way. In the early 1960's an important technology improvement was achieved by Imperial Chemical Industries Ltd. (ICI). They introduced low pressure technology, which was made possible through the development of higher activity catalysts. Since that time, low pressure gas phase methanol process technology has dominated the market. Only in the early 1980's was the potential of liquid phase technology realized by Chem Systems and Air Products and Chemicals, Inc. As result of technology consolidation between both these companies the LPMEOH™ technology was developed, with the financial support of the U. S. Department of Energy (DOE). The concept was proven in over 7,400 hours of test operation in a DOE-owned, 3,200 gallons (U.S.) of methanol per day process development unit located at LaPorte, Texas. (Ref. a). The commercial-scale demonstration plant for the technology has been constructed and is now being commissioned at Eastman Chemical Company's coal gasification facility in Kingsport, Tennessee under the DOE's Clean Coal Technology Program. The LPMEOH™ plant will demonstrate the production of at least 80,000 gallons of methanol per day, and will simulate operation for the IGCC co-production of power and methanol. Construction began in October of 1995 and was, in a record period of 15 months, completed in December of 1996. Commissioning was completed and startup initiated in January of 1997, and will be followed by four years of operation to demonstrate the commercial advantages of the technology.

Air Products and Eastman formed the "Air Products Liquid Phase Conversion Co., L.P." limited partnership to execute the demonstration project. The partnership owns the LPMEOH™ demonstration plant. Air Products manages the demonstration project and provides technology analysis and direction for the demonstration. Air Products also provided the design, procurement, and construction of the LPMEOH™ demonstration plant (i.e., a turnkey plant). Eastman provides the host site, performs the permitting and operation of the LPMEOH™ unit, and supplies the supporting auxiliaries, the synthesis gas, and takes the product methanol.

Most of the product methanol will be refined to chemical-grade quality (99.85 wt % purity via distillation) and used by Eastman as chemical feedstock in their commercial facility. A portion of the product methanol will be withdrawn prior to purification (about 98 wt % purity) and used in the off-site product-use tests.

I. COMMERCIAL APPLICATION

Technology Description

The heart of the liquid phase technology, in this case the LPMEOH™ process, is the slurry bubble column reactor (Figure 1). The liquid medium is the feature that differentiates the LPMEOH™ process from conventional technology. Conventional methanol reactors use fixed beds of catalyst pellets and operate in the gas phase. The LPMEOH™ reactor uses catalyst in powder form,

slurried in an inert mineral oil. The mineral oil acts as a temperature moderator and a heat removal medium, transferring the heat of reaction from the catalyst surface via the liquid slurry to boiling water in an internal tubular heat exchanger. Since the heat transfer coefficient on the slurry side of the heat exchanger is relatively large, the heat exchanger occupies only a small fraction of the cross-sectional area of the reactor. The slurry reactor can thus achieve high syngas conversion per pass, due to its capability to remove heat and maintain a constant, highly uniform temperature through the entire length of the reactor. Thus an essentially exothermic process has been converted to an isothermal process.

Because of the LPMEOH™ reactor's unique temperature control capabilities, it is able to directly process syngas which is rich in carbon oxides (carbon monoxide and carbon dioxide). Gas phase methanol technology would require such a feedstock to undergo stoichiometry adjustment by the water gas shift reaction (to increase the hydrogen content) and carbon dioxide (CO₂) removal (to reduce the excess carbon oxides). In a gas phase reactor, temperature moderation is only achieved by recycling large amounts of hydrogen (H₂)-rich gas, utilizing the higher heat capacity of H₂ gas as compared to carbon monoxide (CO) gas. Typically a gas phase reactor is limited to about 16% CO gas in the inlet to the reactor, in order to limit the conversion per pass to avoid excess heating. Hence recycle ratios of 6 - 10 are typically applied. In contrast, with the LPMEOH™ reactor, CO gas concentrations in excess of 50% have been routinely tested without any adverse effect on the catalyst activity.

A second differentiating feature of the LPMEOH™ reactor is its robust character. The slurry reactor is suitable for rapid ramping, idling, and even extreme stop/start actions. The thermal moderation provided by the liquid inventory in the reactor acts to buffer sharp transient operations that would not normally be tolerable in a gas phase methanol synthesis reactor.

A third differentiating feature of the LPMEOH™ process is that a high quality methanol product is produced directly from syngas which is rich in carbon oxides. Gas phase methanol synthesis, which relies on hydrogen-rich syngas, results in a crude methanol product with up to 20% water by weight. The product from the LPMEOH™ process typically contains only 1% water by weight. This methanol product, coproduced with IGCC, is therefore suitable for many applications, and at a substantial savings in purification costs. The steam produced in the LPMEOH™ reactor is suitable for purification of the methanol product (for upgrading to a higher quality) or for use in the IGCC power generation cycle.

Another unique feature of the LPMEOH™ process is the ability to add fresh catalyst online. Methanol catalysts deactivate at a slow rate. With the LPMEOH™ reactor, spent catalyst slurry may be withdrawn and fresh catalyst slurry added on a periodic batch basis. This allows continuous, uninterrupted operation, i.e. maximum number of streamdays per year, and also the maintenance of a high productivity level in the reactor. Furthermore, choice of replacement rate permits optimization of productivity versus catalyst replacement cost.

Finally the simplicity of reactor construction is an advantage to the LPMEOH™ process.

Other Liquid Phase Reactions

The technology and process characteristics/advantages as described for the LPMEOH™ process above are also applicable to a variety of other exothermic syngas reactions. In essence it is the combination of technology elements such as the following:

- exothermicity of the chemical reaction of syngas to product
- successful reactor engineering and scale up
- selectivity towards desired reaction products and
- maintenance of catalyst(s) activity

which will determine the competitiveness of the liquid phase technology.

Following the successful development of the LPMEOH™ technology, which hereinafter will be used as an example, Air Products, sponsored by DOE, broadened the scope of its liquid phase technology interest. Air Products, together with various subcontractors, further developed and/or improved the liquid phase technology for the following chemical processes:

- 1. New C₁ - chemistry to Methyl Tertiary Butyl Ether (MTBE)
 - 1. a. Liquid Phase Isobutanol/Methanol
 - 1. b. Liquid Phase Isobutylene (LPIBE)
- 2. Liquid Phase Di-Methyl Ether (LPDME)
- 3. Liquid Phase Water Gas Shift
- 4. Liquid Phase Fischer-Tropsch

The new C₁-chemistry to MTBE depends on two critical steps. The first is the efficient production of both methanol and isobutanol direct from syngas, and the second is dehydration of isobutanol to isobutylene. Following laboratory autoclave pioneering and suitable catalyst system(s) determination, the LPIBE technology was proven in the LaPorte Alternative Fuels Development Unit (AFDU). Isobutanol conversion as high as 98% with an isobutylene selectivity of 92% was

achieved. High conversion/selectivity is necessary in this, as in many, processes as the product separation of reaction products is difficult and expensive. The Liquid Phase Isobutanol/Methanol production from synthesis gas is presently under further research/demonstration, as previous successful demonstrations are deemed to operate at too high pressures and/or temperatures.

LPDME has been recognized as a possible spring-board molecule for synthesis of fuels and chemicals. Laboratory tests on a dual catalyst system (to perform both methanol synthesis and dehydration in the same reactor vessel) were successful on a laboratory stirred tank reactor scale. Preliminary economics led to high interest in this liquid phase technology and demonstration in the AFDU in LaPorte. LPDME technology is expected to be Air Products' next step in the commercialization of liquid phase technology. Development/cost improvement activities are ongoing.

IGCC Coproduction Options

The LPMEOH™ process is a very effective technology for converting a portion of the H₂ and CO in an IGCC electric power plant's coal-derived syngas to methanol. The process is very flexible in being able to process many variations in syngas composition. The LPMEOH™ process can be used with an IGCC electric power plant (Ref. b), to provide the once-through methanol production as depicted in Figure 2. The process can be designed to operate in a continuous, baseload manner, converting syngas from oversized gasifiers or from a spare gasifier. The process can also be designed to operate only during periods of off-peak electric power demand to consume a portion of the excess syngas and allow the electricity output from the combined-cycle power unit to be turned down. In this latter circumstance, the gasification unit continues to operate at full baseload capacity, so the IGCC facility's major capital asset is fully utilized.

In either baseload or cycling operation, partial conversion of between 20% and 33% of the IGCC plant's syngas is optimal, and conversion of up to 50% is feasible. The degree of conversion of syngas (or the quantity of methanol relative to the power plant size) determines the design configuration for the LPMEOH™ process. In its simplest configuration, syngas (feed gas) at its maximum available pressure from the IGCC electric power plant is passed once, without recycle through the LPMEOH™ plant (Figure 3), and partially converted to methanol. The unreacted feed gas is returned to the IGCC power plant's combustion turbines.

If greater amounts of syngas conversion are required, different once-through plant design options (Figure 3) are available. The feed gas pressure to the reactor is a prime determinant of the degree of syngas conversion, as shown in Figure 4. Reaction pressure for methanol synthesis design is usually 750 psia or higher. The higher the pressure at which the syngas is available, the greater is the degree of conversion and the lower the conversion cost. The LPMEOH™ process design options for greater syngas conversion are:

- Once-Through, with Feed Gas Compression:

When the feed gas pressure from the IGCC electric power plant is low (e.g. below 750 psia), feed gas compression may be added to the LPMEOH™ process design, to increase reactor productivity and the overall conversion of syngas to methanol.

- Limited Gas Recycle:

One design technique to increase the degree of syngas conversion is to condense out methanol from the reactor effluent and to recycle part of the unreacted feed gas back to the reactor inlet. With the LPMEOH™ process, this simple recycle refers to recycle of CO-rich gas. The recycle ratio required for the LPMEOH™ is moderate, for example, one part unreacted syngas to one part fresh feed gas. This 1 to 1 recycle ratio is usually quite effective in optimizing the methanol production. At higher recycle ratios, little is gained since most of the available H₂ has already been converted to methanol.

- Once-Through with Water Addition:

Of course, the richer the once-through syngas is in CO, the more the production is limited by the availability of H₂. If additional conversion is desired, the LPMEOH™ process design can be altered to generate additional H₂. The inherent shift activity of the methanol catalyst can be utilized to accommodate a modest amount of shift activity within the reactor. This is done by the addition of water, as steam, to the syngas before it passes through the liquid phase methanol reactor. Within the reactor, the additional steam is converted to H₂ which is, in turn, converted to methanol. In the water addition case, the increase in conversion is accompanied with a modest increase of water in the crude methanol product and of CO₂ in the reactor effluent gas.

Any combination of these LPMEOH™ process design options may be used to achieve the desired degree of syngas conversion. There is still no need for upstream stoichiometric adjustment of the feed gas by the water-gas shift reaction and CO₂ removal; so the simplicity of once-through CO-

rich gas processing is retained.

Baseload Coproduction of Methanol and Power

Process design study work for the LPMEOH™ process has been directed towards converting a portion of coal-derived syngas produced in an IGCC electric power plant to methanol. A feed gas containing 35% H₂, 51% CO, 13% CO₂ and 1% inerts (nitrogen) was used for preparing the baseload methanol coproduction economics.

With a given gasification plant size, the IGCC coproduction plant can be designed to accommodate a range of methanol to power output ratios. For example (Ref. c, d), a gasification plant, with two gasifiers of 1735 million Btu (HHV) per hour output each (equivalent to some 2200 tonnes per day of coal input), could be sized for baseload power output of 426 megawatts of electricity (MWe) and for baseload methanol coproduction of 152,000 US gallons per day (G/D). Other methanol and power plant size options for this gasification plant size are shown in Table 1.

Table 1. Methanol Plant to Power Plant Size Ratio			
% of Syngas Converted to Methanol (%)	Baseload Power Plant Size (MWe)	Baseload Methanol Plant Size (G/D)	Methanol Plant to Power Plant Size Ratio (G/D per MWe)
0	500	0	0
13.8	426	152,000	357
20.0	394	210,000	533
30.0	342	330,000	965

The IGCC coproduction plant with 426 MWe of power and 152,000 G/D of methanol is used for the baseload production cost estimate for coproduced methanol, shown in Table 2. If the baseload fuel gas value is \$4.00 per million Btu, then 152,000 G/D of methanol can be coproduced from coal for under 50 cents per gallon.

As expected, the methanol production cost is lower at larger methanol plant sizes. Figure 5 shows the effect of plant size for once-through methanol coproduction. Methanol production costs for two of the LPMEOH™ plant design options for higher syngas conversion: 1 to 1 gas recycle, and 1 to 1 gas recycle with water addition, are also shown.

Today, new methanol plants are being built where natural gas is inexpensive (Chile, Saudi Arabia). These new world scale plants range in size from 700,000 to 900,000 G/D (2000 to 2700 metric tons per day) in size. The economy of scale savings; in natural gas gathering, syngas production, and in methanol storage and ocean transport facilities; drive these plants to a large size. Estimates (Ref. e, f) show that an 836,000 G/D remotely located methanol plant (with the same 20% per year capital charge as in Figure 5), with natural gas at \$0.50 to \$1.00 per million Btu, has a total ex-plant methanol production cost of 46 to 50 cents per gallon. Adding ocean freight, duty and receiving terminal storage typically adds 8 to 10 cents per gallon; giving a total delivered U.S. Gulf Coast methanol cost (Chemical Grade) of 55 to 60 cents per gallon.

Figure 5 is interesting because it provides an unexpected result. Methanol coproduction with IGCC and the once-through LPMEOH™ process does not need large methanol plant sizes to achieve good economics. The gasification plant is already at a large economical scale for power generation; so the syngas production economics are already achieved. Methanol storage and transport economics are also achieved by serving local markets, and achieving freight savings over the competing methanol, which is usually shipped via the U. S. Gulf coast from areas with inexpensive feed gas (like natural gas or associated gas).

The 50 cents per gallon coproduction cost for a 152,000 G/D once-through LPMEOH™ plant size is in local markets competitive with new world scale natural gas based methanol plants. Figure 5 shows an additional 3 to 4 cent per gallon saving for a 365,000 G/D LPMEOH™ plant size. These additional savings might be used to off-set higher freight costs to more distant local customers; while still maintaining a freight and cost advantage over the imported methanol from the Gulf Coast.

The 50 cents per gallon coproduction cost for a 152,000 G/D once-through LPMEOH™ plant size in local markets is competitive with new world scale natural gas-gased methanol plants. Figure 5 shows an additional 3 to 4 cent per gallon savings for a 365,000 G/D LPMEOH™ plant size. These additional savings might be used to offset higher freight costs to more distant local

customers, while still maintaining a freight and cost advantage over the imported methanol from the Gulf Coast.

TABLE 2. Production Cost Estimate for Coproduced Methanol

LPMEOH Plant Capacity: 152,000 gallons per day (500 sT/D)

Capital Investment: \$29 million

Methanol Plant Operation:	Based 7884 hr/yr
Methanol Production (million gall./year):	49.9
<u>Methanol Production Cost</u>	<u>cents/gallon</u>
Syngas cost:	
Feed Gas @ fuel value (\$4.00/mmBtu)	98.7
Unreacted (CO-rich) gas @ fuel value (\$4.00/mmBtu)	(68.4)
Sub-total; net cost of syngas converted:	30.3
Operating cost:	
Catalyst and chemicals	2.6
Export steam	(2.9)
Utilities	0.9
Other (fixed) costs	4.0
Sub-Total; Operating Costs:	4.6
Capital charge @ 20% of investment per year	11.6
Total Methanol Production Cost:	46.5

Basis:

U. S. Gulf Coast Construction, 4thQ 1996 \$

Includes owner costs and 30 days of Product Storage

CO-rich feed gas from IGCC electric power plant at 1000 psia, with 5ppm (max.) sulfur. Once-through

LPMEOH process design with 1562 mmBtu/hr in, 1082 mmBtu out tHHV). Excludes License and

Royalty fee. Air Products is the LPMEOH process technology licensor. Product methanol with 1 wt %

water; Chem. Grade would add 4 to 5 cents per gallon.

II. DEMONSTRATION PLANT - STATUS

Development of the LPMEOH™ technology came to further fruition through cooperation between Air Products, DOE and Eastman Chemical Company under the DOE Clean Coal Technology Program (Ref. g).

Kingsport Site

Eastman has an extensive chemical complex at the Kingsport site, where originally methanol was produced by distillation of wood and later changed to conversion of coal-derived syngas. Coal gasification operations at Kingsport began in 1983. Figure 6 shows an aerial view of Eastman's Kingsport gasification facility. Texaco gasification is used to convert about 1,000 tons-per-day of high-sulfur, Eastern bituminous coal to synthesis gas for the manufacture of methanol, acetic anhydride, and associated products. Air Products provides the oxygen for gasification by a pipeline from an over-the-fence air separation unit. The crude synthesis gas is quenched, partially shifted, treated for acid gas removal (hydrogen sulfide and carbonyl sulfide, and CO₂, via Rectisol), and partially processed in a cryogenic separation unit to produce separate H₂ and CO streams. The H₂ stream is combined with clean synthesis gas to produce stoichiometrically balanced feed to a conventional gas phase methanol synthesis unit. Methanol from this unit is reacted with recovered acetic acid to produce methyl acetate. Finally, the methyl acetate is reacted with the CO stream to produce the prime product, acetic anhydride (and acetic acid for recycle). Figure 7 shows the process block flow diagram for the Kingsport gasification facility including the LPMEOH™ demonstration plant.

LPMEOH™ Demonstration Plant Design

The site available at Kingsport provides a 270 ft. by 180 ft. plot for the demonstration plant and tank truck loading areas. An area next to the site was made available for establishing the

construction trailer, fabrication, and laydown areas. Figure 8 is an aerial view of the site prior to the start of construction. Air Products was responsible for the engineering design and construction of the project. Eastman was responsible for the outside battery limits design and construction, the permitting, and for providing the digital control programming. Eastman reviewed the detailed design of the demonstration plant.

Because the gasification facility produces individual streams of clean synthesis gas, CO, and H₂-rich gas, there is the capability to blend gases and mimic the gas compositions of a range of gasifiers. Hence, the broad applicability of the LPMEOH™ technology could be proven and formed part of an elaborate test program, to be discussed later. Those test objectives also provided a design challenge for the Air Products/Eastman design team. Of primary importance was the integration of the LPMEOH™ demonstration plant within the Kingsport gasification complex. Since the feed composition to the reactor was to be varied from H₂-lean to H₂-rich (25% to 70+%H₂) and the flow to the reactor by at least a factor of two, all of the product and byproduct streams within and outside the battery limits were affected. Control valves and instrumentation for the demonstration plant were required to have functionality over and beyond those for a normal commercial facility. Extreme cases of about twenty different heat and material balances were considered for specification of each piece of equipment, flow measurement device, control valve, and safety relief device.

The DOE approved Eastman's Kingsport, TN facility as the site of the LPMEOH™ Demonstration Plants in October of 1993. Air Products and Eastman worked with the DOE to define the size of the plant and develop a Statement of Work for the LPMEOH™ Demonstration at Kingsport. This Project Definition phase including a cost estimate was completed in October of 1994. Preliminary detailed design work on equipment layouts and development of P&ID's began shortly after this. Full authorization from the DOE for Design and Construction was effective February 1, 1995. The reactor was the first piece of equipment to be placed on order in November of 1994. Equipment deliveries began in November of 1995. The State air permit was received in March of 1996. The DOE completed its National Environmental Policy Act (NEPA) review and issued a Finding of No Significant Impact (FONSI) in June of 1995. Construction at the site began in October of 1995. Construction was essentially completed in December of 1996.

Instrument Loop Checking began in October 1996. Commissioning began in December of 1996, followed by startup in late January of 1997. Thereafter a four-year methanol test operation was started in February of 1997. The operating test program will end in the year 2001. The off-site fuel use tests will be performed over an 18 to 30 month period, beginning in May of 1998.

III. DEMONSTRATION PLANT - TEST PLANS

Methanol Operations - Demonstration Test Plan

Three key results will be used to judge the success of the LPMEOH™ process demonstration during the four years of operational testing:

- Resolution of technical issues involved with scaleup and first time demonstration for various commercial-scale operations
- Acquisition of sufficient engineering data for commercial designs
- Industry acceptance

The demonstration test plan has been established to provide flexibility in order to meet these success criteria. Annual operating plans, with specific targeted test runs, will be prepared and revised as necessary. These plans will be tailored to reflect past performance as well as commercial needs. User involvement will be sought.

The LPMEOH™ operating test plan outline, by year, is summarized in Table 3. The demonstration test plan encompasses the range of conditions and operating circumstances anticipated for methanol coproduction with electric power in an IGCC power plant. Since Kingsport does not have a combined-cycle power generation unit, the tests will simulate the IGCC application. Test duration will be emphasized in the test program. The minimum period for a test condition, short of the rapid ramping tests, is 2 weeks. Numerous tests will have 3-6 week run periods, some 8-12 weeks, and a few key basic tests of 20 to 30 weeks.

Table 3. LPMEOH™ Demonstration Test Plan Outline

Year 1

- Catalyst Aging
 - Catalyst Life Versus LaPorte process development unit and Lab Autoclaves
- Process Optimization / Maximum Reactor Productivity
 - Catalyst Slurry Concentration
 - Reactor Slurry Level
 - Catalyst Slurry Addition Frequency Test
- Establishment of Baseline Condition

Years 2 & 3

- Catalyst Slurry Addition and Withdrawal at Baseline Condition
- Catalyst Attrition/Poisons/Activity/Aging Tests
- Simulation of IGCC Coproduction for:
 - 1. Synthesis Gas Composition Studies for Commercial Gasifiers
 - Texaco, Shell, Destec, British Gas/Lurgi, Other Gasifiers
 - 2. IGCC Electrical Demand Load Following:
 - Rapid Ramping, Stop/Start (Hot and Cold Standby)
 - 3. Additional Industry User Tests
- Maximum Catalyst Slurry Concentration
- Maximum Throughput/Production Rate

Year 4

- Stable, extended Operation at Optimum Conditions
- 99% Availability
- Potential Alternative Catalyst Test
- Additional Industry User Tests

Applications for the Coproduced Methanol Product

The methanol coproduction process studies show that the LPMEOH™ process can produce a clean high quality methanol product at less than 50 cents per gallon from an abundant, non-inflationary local fuel source (coal). As previously indicated the quality of the methanol produced approaches closely that of chemical grade methanol. This allows in certain applications for limited distilling of the product and, hence, another advantage for the LPMEOH™ process. Serving local markets, the methanol coproduced at central IGCC electric power plants, can be a valuable premium fuel or fuel feedstock for many applications, such as:

1. An economical hydrogen source for small fuel cells being developed for transportation applications. Methanol is a storable, and transportable, liquid fuel which can be reformed under mild conditions to provide an economical source of hydrogen for fuel cells.
2. Reformed under mild conditions, liquid phase methanol may be an economical hydrogen or carbon monoxide source for industrial applications.
3. A substitute for chemical grade methanol being used for MTBE manufacture.
4. An environmentally advantaged fuel for dispersed electric power stations. Small packaged power plants (combustion turbine, internal combustion engine, or fuel cell) provide power and heat locally, at the use point; without any competition like natural gas pipelines and high voltage power lines. Since methanol is an ultra-clean (zero sulfur) fuel which burns with very low (better than natural gas) emissions of nitrogen oxides, the incremental power is very clean.
5. Finally, the coproduced methanol may be used by the utility owning the IGCC facility (see Figure 2). Potential uses are: a) as a backup fuel for the IGCC plant's main gas turbines; b) as a fuel for a separate, dedicated cycling combined-cycle unit at the same site; c) as the fuel exported to the utility's distributed power generation system(s); or d) as the transportation fuel for the utility's bus or van pool. Since the methanol is derived from the coal pile, the IGCC facility can be truly independent and self-sufficient for fuel needs. In addition, should the external prices for methanol command higher value to the IGCC plant's owner, the methanol can be exported for additional revenues.

Many of the applications listed above are embryo developments. Their ultimate market size potential for transportation applications, for industrial applications and for distributed power generation could become large. The methanol product specification for the applications is not adequately known. Therefore, part of the LPMEOH™ demonstration project's program is to confirm the suitability of the methanol product for these (and other) uses. Product-use tests will allow development of final methanol product specifications. During the demonstration, in the 1998 to 2000 time-frame, about 400,000 gallons of the "as-produced from CO-rich syngas" methanol will be available for off-site product-use testing. The final off-site product-use test plan is now under development. More details will be provided to interested parties.

CONCLUSION

The LPMEOH™ process is now being demonstrated at commercial scale under the DOE Clean Coal Technology Program. The demonstration plant, located at Eastman Chemical Company's Kingsport, Tennessee coal gasification facility site, will produce at least 80,000 gallons-per-day of methanol from coal-derived synthesis gas. Startup was effected in January of 1997, followed by a four-year demonstration test period beginning in February of 1997.

Successful demonstration of the LPMEOH™ technology will add significant flexibility and dispatch benefits to IGCC electric power plants, which have traditionally been viewed as strictly a baseload power generation technology. Now, central clean coal technology processing plants, making coproducts of electricity and methanol, can meet the needs of local communities for dispersed power and transportation fuel. The LPMEOH™ process provides competitive methanol economics at small methanol plant sizes, and a freight and cost advantage in local markets vis-a-vis large remote gas methanol. Methanol coproduction studies show that methanol at less than 50 cents per gallon can be provided from an abundant, non-inflationary local fuel source (coal). The coproduced methanol may be an economical hydrogen source for small fuel cells, and an environmentally advantaged fuel for dispersed electric power.

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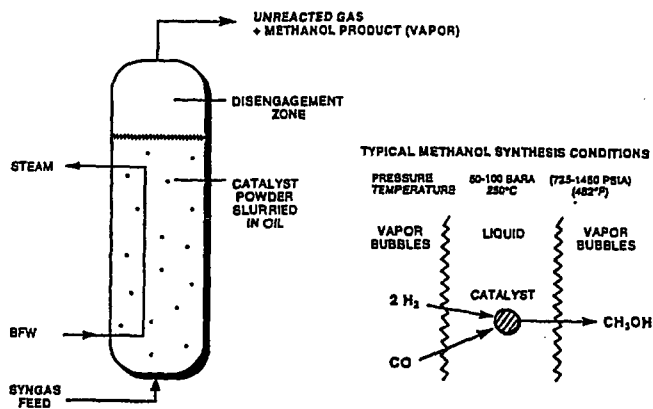


Figure 1. LPMEOH™ Reactor and Reaction Schematics

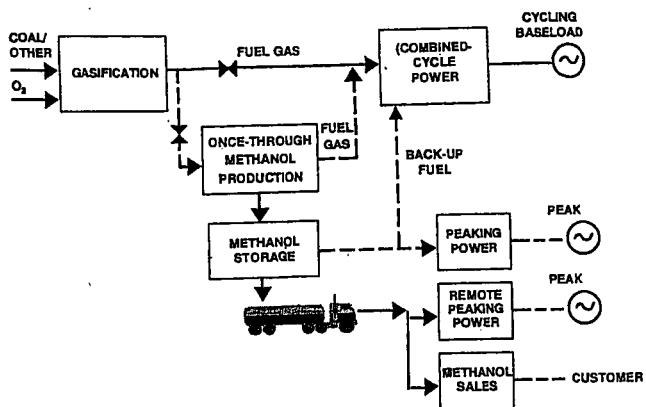


Figure 2. Once-through Methanol Coproduction with IGCC Electric Power

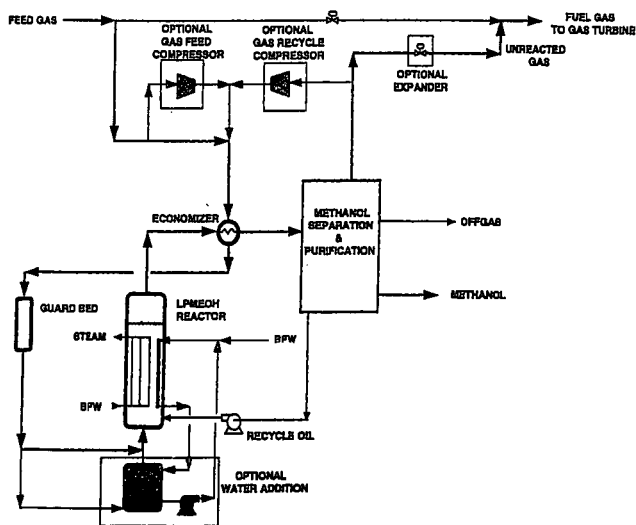


Figure 3. Once-through LPMEOH™ Process Design Options

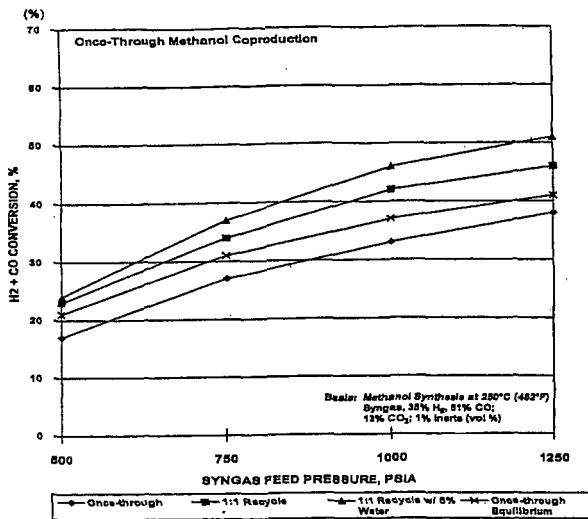


Figure 4. Synthesis Gas Conversion to Methanol

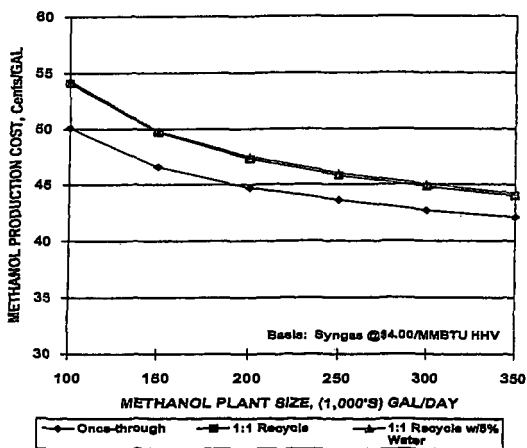


Figure 5. Coproduct Methanol Cost versus Methanol Plant Size.

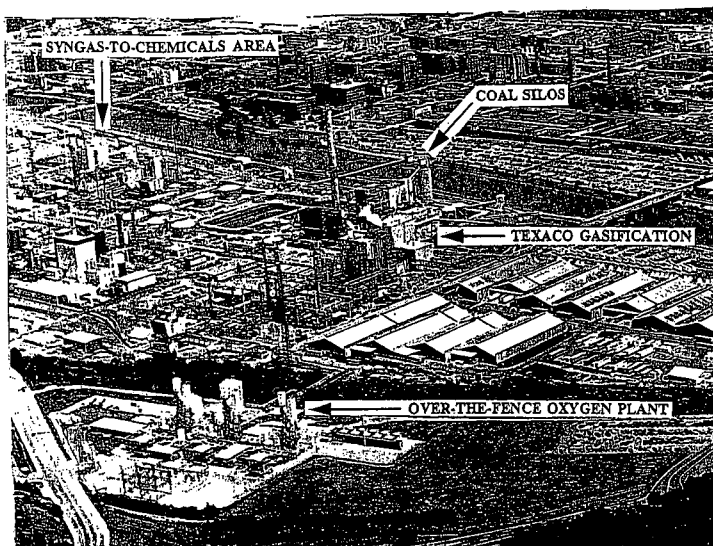


Figure 6. Aerial View of Eastman's Kingsport Complex

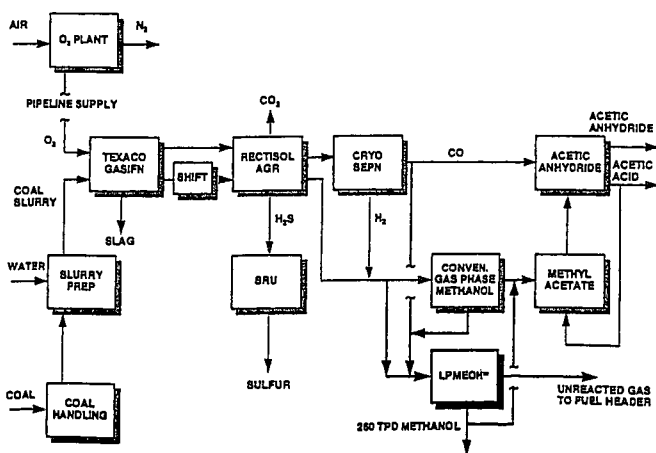


Figure 7. Process Block Flow Diagram of Kingsport Facility Including LPMEOH™ Demonstration Plant.

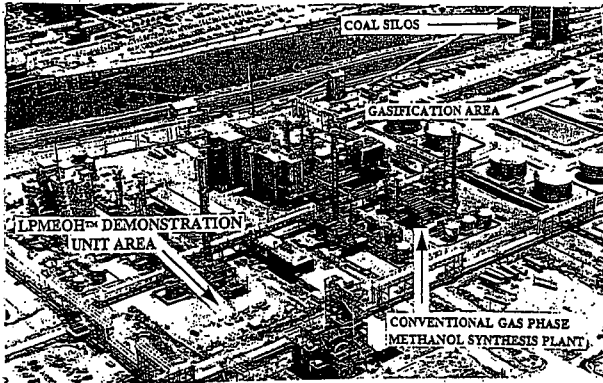


Figure 8. Aerial View of the Site for the LPMEOH™ Demonstration Plant

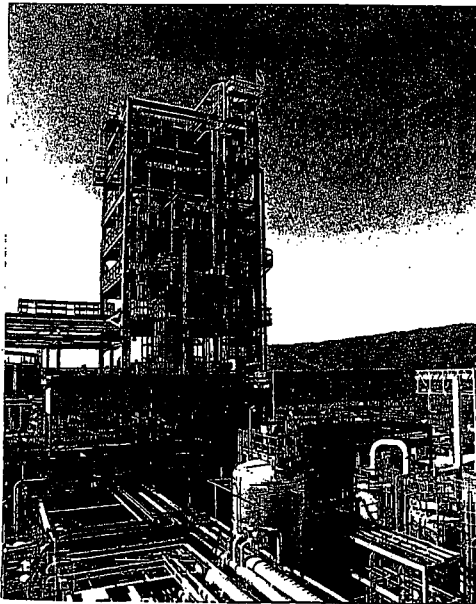


Figure 9. Photograph of the installed LPMEOH™ Demonstration Plant